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Nucleus-Nucleus Collisions at Very High Energies

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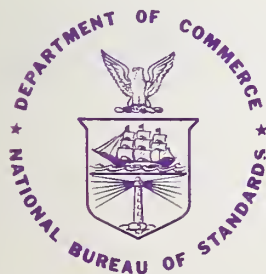
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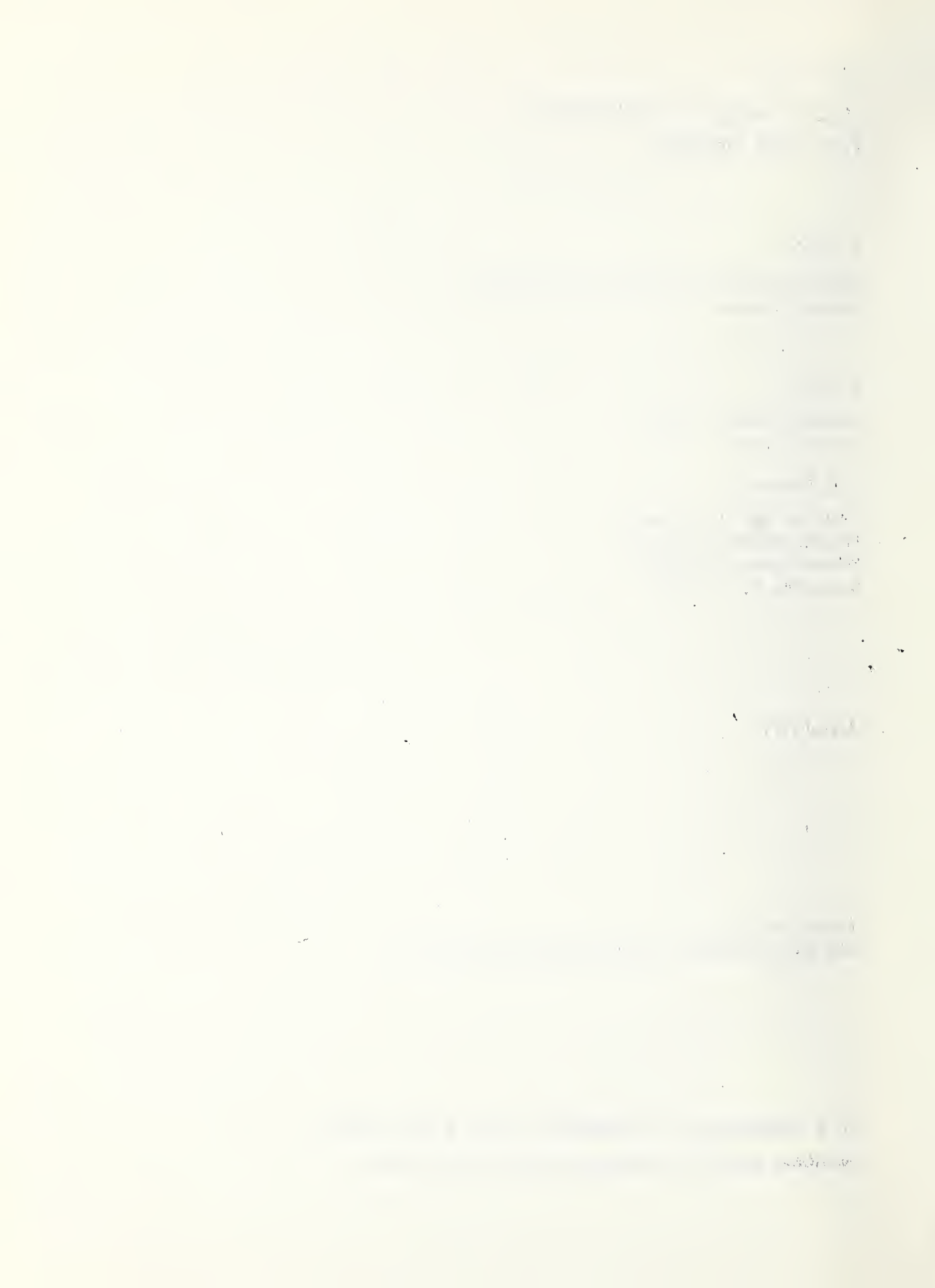
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I. Introduction

It has been stressed many times that nucleus-nucleus collisions at high energies are worth investigating both theoretically and experimentally [1-6] because virtually nothing is known about this exotic field and, at the same time, the theoretical models one may envisage give several simple and definite predictions. The present note discusses one such model which was originally proposed for hadron-nucleus scattering [7] but can be straightforwardly generalized to nucleus-nucleus collisions. The main purpose of this note is to spell out this generalization and to give the formulae for the total cross sections, diffractive production cross sections, and inclusive single particle distributions in multiparticle production in nucleus-nucleus collisions. One of the important conclusions of this analysis is that the measurements of the relations between various total cross sections proposed in refs. [3-6] could test the model of ref. [7].

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2. The model.

We shall work in the c.m. system of the two nuclei containing A and B nucleons. The S matrix for such collision is, according to the model of ref. [7] ,

$$S_{AB} = \prod_j^A \prod_l^B S_{jl} = \prod_j^A \prod_l^B [1 - \Gamma_{jl} + i T_{jl}] \quad (2.1)$$

where S_{jl} is the S matrix for the j -th nucleon from A colliding with the l -th nucleon from B. As in [7], the "absorptive" part, Γ_{jl} , which describes both elastic scattering and diffractive production, is generated by the driving term T_{jl} responsible for non-diffractive multiple production processes ($T_{jl} = T_{jl}^\dagger$) , and the unitarity of S_{jl} gives

$$2\Gamma_{jl} = \Gamma_{jl}^2 + T_{jl}^2 \cong T_{jl}^2. \quad (2.2)$$

Again, following the approach of ref. [7], we accept that the production processes (in fact all possible processes) are completely coherent over the two nuclei and this fact is incorporated into our description in a relativistically invariant manner by making the operators of Eqs. (2.1) and (2.2) dependent only on the transverse degrees of freedom. In the present simple version we shall use only the impact parameter

and the transverse distances of the individual nucleons from the axis of cylindrical symmetry of the collision as these transverse degrees of freedom.

One should also keep in mind that, henceforth, we shall deal only with sum rules in which the momentum transfer between the two nuclei (more precisely: between the two groups of particles which emerge from the collision and go to the left and to the right in the c.m. system) is integrated over and the sum performed over all possible excitations (of nuclei and of their components: nucleons). Cross sections for specific processes are obtained, in the present approach, through the introduction of suitable projection operators into such sums and integrations. Note that in this approach one completely avoids dealing with the longitudinal momentum transfers in the process of multiple collisions: for example, as can be seen in Sec. C on inclusive cross sections, the dependence on the longitudinal momenta comes only through the final expression, (2.6), where they are accounted for in the "elementary" hadron-nucleon inclusive cross section, $d\bar{\sigma}_i^{(N)}(p_i)$.

Assuming the same properties of the individual matrices as in ref. [7] and going through algebra analogous to that used in the case of hadron-nucleus collisions [7], we readily obtain:

A. Elastic scattering and coherent diffractive production.

The amplitude for both processes at the impact parameter

b reads (to lowest order in diffractive production)

$$\begin{aligned}
 & \langle n \rangle \phi_i^{(A)} \phi_i^{(B)} \left| \left\{ 1 - \prod_{j=1}^A \prod_{l=1}^B \left[1 - \gamma_{jl} \left(\delta_{jl} - \delta_{jl}^{(A)} + \delta_{jl}^{(B)} \right) \right] \right\} \right| 0; \phi_i^{(A)} \phi_i^{(B)} \rangle \\
 &= \langle \phi_i^{(A)} \phi_i^{(B)} \left| \left\{ 1 - \prod_{j=1}^A \prod_{l=1}^B \left[1 - \gamma_{jl} \left(\delta_{jl} - \delta_{jl}^{(A)} + \delta_{jl}^{(B)} \right) \right] \right\} \right| \phi_i^{(A)} \phi_i^{(B)} \rangle \delta_{n0} \\
 &+ \varepsilon \sum_{j=1}^A \sum_{l=1}^B \langle \phi_i^{(A)} \phi_i^{(B)} \left| \prod_{k \neq j}^A \prod_{r \neq l}^B \left[1 - \gamma_{kr} \left(\delta_{kr} - \delta_{kr}^{(A)} + \delta_{kr}^{(B)} \right) \right] \right| \phi_i^{(A)} \phi_i^{(B)} \rangle \\
 &\quad \times \langle n | d_{je} | 0 \rangle. \quad (2.3)
 \end{aligned}$$

In this formula the absorptive part of the matrix S_{je} was split into the elastic and diffractive inelastic parts

$$\Gamma_{je} = \gamma_{je} + \varepsilon d_{je}$$

where γ_{je} is diagonal (this is the "profile" of the Glauber model) and the off-diagonal correction responsible for diffractive production is assumed to be small. In ref. [7] such a form for Γ_{je} was explicitly obtained from the bremsstrahlung model of multi-particle production [8].

It was also suggested by the general considerations of ref. [9]. In Eq. (2.3) the states are labelled by the nuclear wave functions of both nuclei ($\phi^{(A)}, \phi^{(B)}$) and by the produced

particles, schematically denoted (n) . The first part of the r.h.s. of (2.3) gives the well known nucleus-nucleus high energy elastic scattering amplitude [1]. Note that ^{the} second part of the r.h.s. of (2.3), which gives diffractive production, is proportional to AB , which means that the cross sections have a $A^2 B^2$ dependence. Hence it would seem that diffractive production in nucleus-nucleus collisions may contribute more significantly to, e.g., one particle inclusive distributions (see below) than in the case of hadron-nucleus collisions, where $B = 1$.

B. The total cross sections. Similarly, as in [7], after employing closure $\sum_n \sum_{f,f'} |n\rangle \phi_f^{(A)} \phi_{f'}^{(B)} \langle \phi_f^{(A)} \phi_{f'}^{(B)} | n \rangle = 1$ and integrating over the momentum transfer between the two nuclei, we obtain the following formula for the total nucleus-nucleus cross section:

$$\begin{aligned} \sigma_T &= \int d^2 b \langle 0; \phi_i^{(A)} \phi_i^{(B)} | (1 - S_{AB}^\dagger(\frac{b}{w}; \underline{A}^{(A)}, \underline{A}^{(B)})) (1 - S_{AB}(\frac{b}{w}; \underline{A}^A, \underline{A}^B)) | 0; \phi_i^{(A)} \phi_i^{(B)} \rangle \\ &= 2 \int d^2 b \langle 0; \phi_i^{(A)} \phi_i^{(B)} | [1 - \text{Re } S_{AB}(\frac{b}{w}; \underline{A}^{(A)}, \underline{A}^{(B)})] | 0; \phi_i^{(A)} \phi_i^{(B)} \rangle \end{aligned} \quad (2.4)$$

where we employed unitarity: $S_{AB}^\dagger S_{AB} = 1$. Again, as in [7], the total cross section is, to zeroth order in ϵ ,

the same as that given by the Glauber model, refs. [1,3,4], and all the relations between the total cross sections proposed in refs. [3,4,5,6], when compared with experiment, will provide a test for the multiparticle production model proposed in ref. [7] and used here.

C. Inclusive single particle distribution in multiparticle production in nucleus-nucleus collisions. We again follow

the same algebra as in [7]:

$$\begin{aligned}
 d\bar{\sigma}_1^{(AB)}(p_1) &= \frac{dp_1}{E_1} \sum_n n \int d\sigma_n(p_1, \dots, p_n) \frac{dp_2}{E_2} \dots \frac{dp_n}{E_n} \\
 &= \frac{dp_1}{E_1} \int d^2k <0; \phi_i^{(A)} \phi_i^{(B)} | [1 - S_{AB}^+(k; \underline{A}^{(A)}, \underline{A}^{(B)})] \rangle \\
 &\quad \langle \alpha^+(p_1) \alpha(p_1) [1 - S_{AB}(k; \underline{A}^{(A)}, \underline{A}^{(B)})] | 0; \phi_i^{(A)} \phi_i^{(B)} \rangle.
 \end{aligned}
 \tag{2.5}$$

The commutation relations $[a(p_i), S_{ij}]$ were worked out in [7] for the case of the hadronic bremsstrahlung model. When we employ them, we again obtain the result that the "diagonal" terms give the leading contribution:

$$d\bar{\sigma}_1^{(AB)}(p_1) = AB d\bar{\sigma}_1^{(N)}(p_1) \tag{2.6}$$

and the non-diagonal contributions appear to be small.

The same qualifications made regarding Eq. (11) of ref. [7], viz., that corrections are to be expected in the very forward direction, can be made here. However, we would like to emphasize the following point. In performing the algebraic operations which lead to (2.6) or Eq. (11) of ref. [7] one neglects energy-momentum conservation in S_0 , which results in suppressing diffractive production. Hence neither Eq. (2.6) nor Eq. (11) of ref. [7] contain contributions to $d\bar{\sigma}_1^{(n)}(p_i)$ coming from diffractive production. In the case of hadron-nucleus interactions this simplification may still be not too bad, but, as has already been pointed out in this note, in the case of nucleus-nucleus collisions it is more serious. It would seem that one could estimate the relevant corrections starting directly from Eq. (2.3). In any case one should expect the relation (2.6) to fail in the extreme forward and backward directions, which are populated by products of diffractive processes.

In concluding, one may say that one can literally take over the model of ref. [7] and extend it trivially to the case of nucleus-nucleus scattering just as ^{the} Glauber model for hadron-nucleus elastic scattering can be extended to nucleus-nucleus elastic scattering.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.) A model for high energy nucleus-nucleus collisions is presented. Formulae are given for the total cross sections, diffractive productive cross sections, and inclusive single particle distributions in multiparticle production in nucleus-nucleus collisions. It is noted that measurement of the relations between a few nucleus-nucleus total cross sections could be used to test this model.			
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